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# REGIONAL STRUCTURE AND FUNCTION IN BRONCHIECTASIS[1, 2, 3]

## A Correlative Study Using Bronchography and $^{133}Xe$

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### INTRODUCTION

Bronchiectasis can be defined as a condition in which one or more bronchi are chronically dilated. Although the findings on history, physical examination, and plain chest films are helpful, bronchography is a necessary diagnostic examination for accurate assessment of the distribution, severity, and course of the disease.

Results of complex tests of pulmonary function have been reported for patients with bronchiectasis (1, 2). However, because these patients often have other lung disease, only broad generalizations can be made at present regarding correlations between defects in over-all lung function and the type and extent of the lesion (3). Techniques using $^{133}Xe$ allow assessment of regional function; such measurements might be profitably combined with the assessment of regional anatomy obtained by bronchography. This report describes regional lung functions in 8 patients with bronchiectasis and compares these results with bronchographic findings.

### MATERIALS AND METHODS

There were 5 females and 3 males in this series ranging in age from 19 to 61 years (table 1). Six of the 8 patients had had both cough and sputum for more than 19 years. Five of the 8 could date the onset of symptoms to pneumonia; one, to aspiration of a chicken bone. Four patients had been suspected of having other lung disease: chronic bronchitis in Patient 1, bronchitis and tuberculosis in Patient 7, and bronchial asthma in Patient 4. All subjects except Patient 4 underwent routine pulmonary function tests, as well as the other studies reported, during the same hospital admission. In all patients measurements were made of vital capacity (VC), the forced expiratory volume at 1.0 sec ($FEV_1$), and steady-state diffusing capacity ($D_{LCO}$). In addition, mixing efficiency (ME) was measured in 2 patients. The techniques of measurement and predicted normal values have been described elsewhere (3).

*$^{133}Xe$ techniques*: All patients were studied in the supine position with 4 or 5 scintillation counters positioned posteriorly under each lung. The counter positions ranged from apex to base according to a 6-foot anteroposterior chest roentgenogram of the supine patient. Tubular lead collimators, 17 cm in length, were applied to these counters; the output of each scintillation counter was recorded on a multichannel magnetic tape recorder and displayed later through counting rate meters onto a direct writer (4).

The patients breathed through a mouthpiece connected to a two-way tap, which in turn could be connected to either an open or a closed breathing circuit. The closed circuit consisted of a valveless spirometer with a mixing motor, a $CO_2$ absorber, and a scintillation counter to monitor $^{133}Xe$ concentration in the spirometer. The open circuit consisted of a small breathing valve; the inspired line contained a dry gas meter, which monitored ventilation, and in the expired line, a mixing box and scintillation counter monitored mixed expired $^{133}Xe$.

The patient was carefully positioned over the chest counters, and after becoming familiar with the equipment, underwent two procedures during quiet breathing: (*1*), a five- or ten-minute period of rebreathing $^{133}Xe$ in air from the closed circuit; (*2*) a five- or ten-minute constant continuous intravenous infusion of $^{133}Xe$ dissolved in saline while breathing through the open circuit. After five or ten minutes, $^{133}Xe$ administration was stopped, and the patient was allowed to wash out intrapulmonary isotope. In most patients, $^{133}Xe$ infusion was terminated by rapidly flushing the infusion line with 20 to 30 ml of saline. Finally, two separate slug injections of a known amount of $^{133}Xe$ in saline were given intravenously during breath holding at functional residual capacity.

| Patient No. | S |
|---|---|
| 1 | M |
| 2 | F |
| | |
| | .. |
| 3 | F |
| 4 | F |
| 5 | M |
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| 7 | M |
| 8 | F |

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TABLE 1

CLINICAL DATA ON 8 PATIENTS IN STUDY

| Patient No. | Sex and Age | Years with Cough and Sputum | Predisposing Disease | Other Disease |
|---|---|---|---|---|
| 1 | Male 61 | 40 | None | Chronic bronchitis |
| 2 | Female 33 | 4 | Bronchopneumonia in childhood; recurrent lower respiratory tract infections | None |
| 3 | Female 25 | 2 | Pneumonia | None |
| 4 | Female 39 | 30 | Cough and wheezing since early childhood | "Bronchial asthma"; chronic suppurative otitis media; latent diabetes mellitus |
| 5 | Male 26 | 20 | Bronchitis and pneumonia at 6 years | None |
| 6 | Female 32 | 25 | Pneumonia, age 7 | None |
| 7 | Male 41 | 21 | Aspiration chicken bone, 1945 | Chronic bronchitis; pulmonary fibrosis; old pulmonary tuberculosis; post left lower lobe resection; cor pulmonale |
| 8 | Female 19 | 19 | Pneumonia at 6 months | None |

To avoid errors due to count rates from $^{133}Xe$ in the subclavian vessels during injections, the uppermost counters were positioned 5 cm below the lung apex, visible injection artefacts were subtracted, and injections were made as centrally as possible—usually in the axillary vein. Count rates collected from lung regions during these procedures allowed independent assessment of regional ventilation-perfusion ratios ($\dot{V}_A/\dot{Q}$), regional blood flow per unit volume ($\dot{Q}/V$), and regional ventilation per unit volume ($\dot{V}/V$).

Regional $\dot{V}_A/\dot{Q}$ during tidal breathing may be calculated if it is assumed that steady states regarding $^{133}Xe$ exchange across the lungs exist in the latter part of both $^{133}Xe$ infusion and rebreathing (5). Under such circumstances

$$\dot{V}_A/\dot{Q} = \frac{C_{\bar{v}}U_I}{F_IU_p} \quad (1)$$

where $U_I$ is the regional count rate during rebreathing, $U_p$ is the regional count rate during infusion, $C_{\bar{v}}$ is mixed venous concentration during infusion, and $F_I$ is the inspired $^{133}Xe$ concentration at the end of rebreathing. Each of these quantities was measured except $C_{\bar{v}}$, which was computed as equal to the $^{133}Xe$ injection rate divided by the cardiac output. In all subjects except Patients 2, 3, and 7, cardiac output was measured by dye dilution technique (6, 7). Normal values for cardiac output were used in the calculations for patients in whom this measurement was not made. Since $C_{\bar{v}}$ is the same for all regions in one individual, its value does not influence relationships among regional $\dot{V}_A/\dot{Q}$ in the same subject, but the estimate of $C_{\bar{v}}$ is necessary for values of absolute $\dot{V}_A/\dot{Q}$ for all regions and, therefore, for comparison between subjects.

Regional $\dot{V}/V$ was evaluated by examining washout of intrapulmonary $^{133}Xe$ after both the rebreathing and the infusion procedures (8). The time (in minutes) necessary for regional count rates to fall to one half of their initial, prewashout values ($T_{1/2}$) was measured for each chest counter. $T_{1/2}$ is inversely related to ventilation per unit volume, and $\dot{V}/V$ was computed as the reciprocal of $T_{1/2}$. Although absolute values for $\dot{V}/V$ are influenced by ventilation and cannot be regarded as quantitatively correct, comparison of regional $\dot{V}/V$ in each subject is valid.

Regional $\dot{Q}/V$ was calculated from regional count rates after slug injections of isotope. These regional count rates were converted to regional concentrations using data derived from the rebreathing procedure (4, 9). Regional concentrations were then indexed in such a way that mean regional $\dot{Q}/V$ in each subject approximated 100.

In normal subjects studied under these conditions no regional differences in $\dot{V}_A/\dot{Q}$, $\dot{V}/V$, or $\dot{Q}/V$ should be apparent.

Although values for $\dot{V}/V$ reflected regional

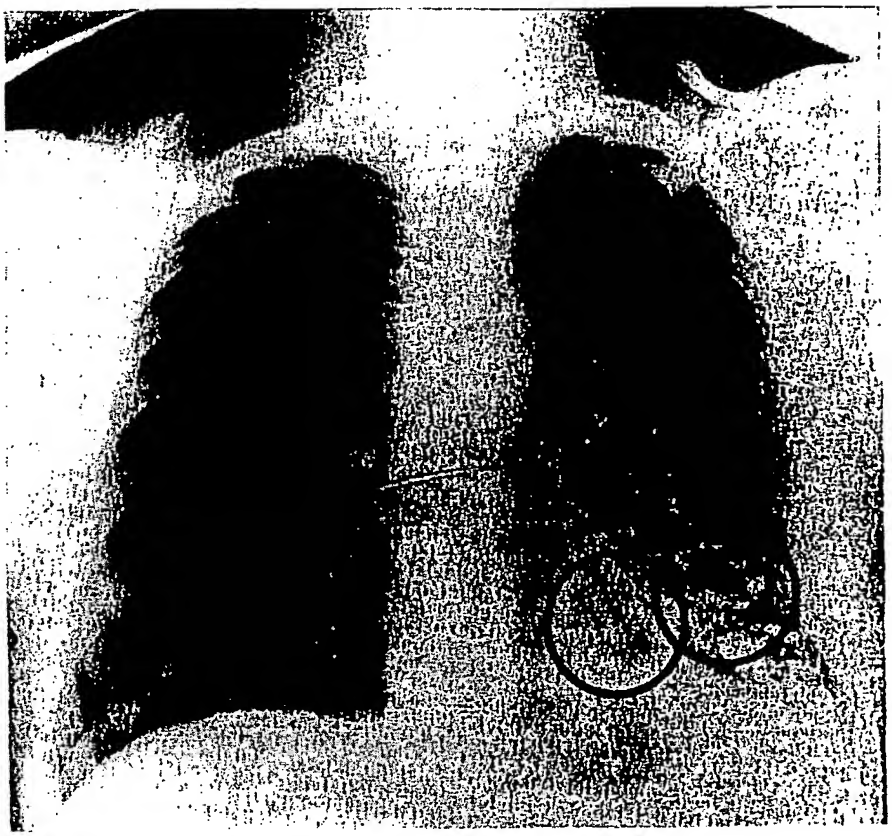

FIG. 1. Left bronchogram of Patient 5, with 5-cm diameter rings in place delineating the bronchographic regions assessed. The rings were placed so as to duplicate the $^{133}Xe$ counter fields in the mid-coronal plane.

differences for each patient, because of differences in over-all ventilation and FRC, intersubject comparison using values of $\dot{V}/V$ alone is not valid. Therefore, in each patient the mean $\dot{V}/V$ of regions considered normal (*see* bold print in table 4) was calculated for each patient, and all regional values of $\dot{V}/V$ in that patient were then expressed as a per cent of this mean; these indices have been termed relative regional ventilation. For the purposes of comparing the distributions of ventilation and perfusion, relative regional perfusion was similarly computed by comparing in each patient all regional $\dot{Q}/V$ with the mean $\dot{Q}/V$ of normally ventilated regions. It should be pointed out that the selection of normal regions was arbitrary. In general, regions that produced high values for $\dot{V}/V$ were designated normal, and it is likely that some regions not designated normal were not in fact diseased. However, relative regional ventilation and relative regional perfusion were computed only for purposes of data presentation; a different approach to these computations would not affect the results of these studies.

*Bronchographic interpretation*: The bronchograms were interpreted according to the classification of Reid (10), in which cylindrical, varicose, and saccular types were described and correlated with progressive reduction of peripheral subdivisions. Overlap of types of bronchiectasis was frequently seen, and it was not uncommon, for example, to find varicose and saccular, or cylindrical and varicose deformities existing in the same lobe or in different lobes in the same subject. The interpretation of regional abnormalities in the bronchograms had, therefore, to take into account the possibility of such overlap.

Bilateral bronchograms of satisfactory quality were available in each case except that of Patient 8, in whom only a right-sided bronchogram had been obtained prior to her development of respiratory failure. Four or five regions were evaluated in each lung. Each region was delineated by a ring 5 cm in internal diameter, which represented the estimated size of the $^{133}Xe$ counter field in the mid-coronal plane (figure 1). The rings were positioned on the bronchogram by means of the same coordinates that had been used to set the position of the scintillation counters for the xenon study. The center of each ring, therefore, coincided with the center of the corresponding counter. In addition to the anteroposterior films, the lateral oblique and spot bronchograms were all scrutinized to facilitate recognition of bronchiectatic areas. Changes in the bronchograms consistent with the presence of chronic bronchitis (11) were also noted. The abnormalities noted within each lung region were then graded numerically by one of the writers (J.H.), who at the

time of the bronchographic assessments had no knowledge of the results of the xenon studies. The numerical system of scoring bronchographic abnormalities is shown in table 2.

## Results

Results of routine pulmonary function tests are shown in table 3. As Patient 2 was studied twice, the tests done before each study are shown. As might be expected, VC and $FEV_1$ were commonly reduced; the amount of impairment indicated by these tests ranged from severe (Patients 7 and 8) to virtually nil (Patient 5). Of interest is the fact that $D_{LCO}$ was definitely abnormal in most cases. Only Patients 1, 2b, and 3 had normal $D_{LCO}$. Mixing efficiency was low in the 2 subjects who underwent this test.

Results of regional bronchographic evaluation together with results of the $^{133}Xe$ studies are shown in table 4. No regions with pure cystic bronchiectasis (grade 6) were seen. Comparison of bronchographic scores with regional $\dot{V}/V$ (the mean of the separate values measured during washout after infusion and after rebreathing) reveals good general agreement except in Patient 1 (*see* p. 602). Regions that showed abnormalities on bronchography were less well ventilated than those that did not. In study 2a, regions $R_{2\text{-}6}$ showed bronchiectasis and demonstrated the lowest $\dot{V}/V$ in this study. In study 2b, $R_5$ was thought to demonstrate abnormality on the bronchogram, and this region was underventilated. Patients 3 to 5 had bronchiectasis at the left base, and this region showed a sharp decrease in ventilation. Patients 6 and 8 demonstrated bilateral basal bronchiectasis, with additional involvement of the right apex in Patient 8. All of these regions showed sharply curtailed ventilation. Unfortunately, only right lung bronchograms were available for Patient 7. The entire lung was involved to some extent by bronchiectasis, but the apex showed considerable preservation of function, and it is possible that this region was functioning normally. Patient 1 was exceptional in that normal ventilation was present in a region ($R_4$) that had cylindrical bronchiectasis. This patient also had roentgenographic evidence of chronic bronchitis as shown by dilated mucous glands with some irregularity of the bronchial margins (11).

Although most bronchiectatic regions were hypoventilated, all hypoventilated regions were by no means bronchiectatic. Anatomically normal regions adjacent to those with bronchiectasis frequently produced low $\dot{V}/V$ (table 4). Thus, there was a fairly consistent tendency for the geographic extent of abnormality to be larger when assessed by $^{133}Xe$ than by bronchography.

In addition, the first study on Patient 2 (study 2a) demonstrated decreased ventilation in $L_{3\text{-}5}$ despite an absolutely normal bronchogram, which had been done 48 hours before the

TABLE 2
NUMERICAL SYSTEM USED IN EVALUATING BRONCHOGRAMS

| Anatomic Lesion | Numerical Value |
|---|---|
| No abnormality | 1 |
| Changes consistent with bronchitis (No diagnostic evidence of bronchiectasis) | 1B |
| Cylindrical bronchiectasis | 2 |
| Cylindrical and varicose bronchiectasis | 3 |
| Varicose bronchiectasis | 4 |
| Varicose and cystic bronchiectasis | 5 |
| Cystic bronchiectasis | 6 |

TABLE 3
PULMONARY FUNCTION TESTS

| Patient | Predicted Normal Values in Brackets | | | |
|---|---|---|---|---|
| | VC (*liter*) | $FEV_1$ (*liter*) | $D_{LCO}$ (*ml/min/mm Hg*) | ME (%) |
| 1 | 2.65 (3.70) | 1.11 (2.20) | 17.4 (13.3) | |
| 2a | 2.81 (3.45) | 1.88 (2.53) | 13.6 (18.7) | |
| 2b | 3.60 (3.45) | 2.52 (2.99) | 15.0 (18.7) | |
| 3 | 2.36 (3.68) | 1.95 (1.98) | 17.9 (19.7) | 46 (65) |
| 5 | 4.87 (4.95) | 4.04 (4.04) | 16.6 (23.3) | |
| 6 | 2.00 (3.65) | 1.44 (1.66) | 11.6 (19.2) | |
| 7 | 2.76 (4.28) | 1.16 (2.29) | 7.8 (19.3) | |
| 8 | 2.15 (3.42) | 1.13 (1.80) | 9.4 (18.9) | 21 (70) |

TABLE 4

RESULTS OF $^{133}$XENON STUDIES IN PATIENTS WITH BRONCHIECTASIS

| Patient No. | Index | Right Lung | | | | | Left Lung | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Apex $R_1$ | $R_2$ | $R_3$ | $R_4$ | Base $R_5$ | Apex $L_1$ | $L_2$ | $L_3$ | $L_4$ | Base $L_5$ |
| 1 | $\dot{V}_A/\dot{Q}$ | 0.56 | 0.59 | 0.60 | 0.60 | 0.64 | 0.55 | 0.64 | 0.59 | 0.49 | 0.59 |
| | $\dot{V}/V$ | 2.29 | 2.63 | 2.36 | 2.47 | 1.60 | 2.23 | 2.22 | 2.56 | 1.89 | 0.98 |
| | $\dot{Q}/V$ | 99 | 98 | 100 | 115 | 103 | 87 | 89 | 88 | 88 | 97 |
| | BrS* | 1 | 1 | 1 | 2 | 1B | 1 | 1 | 1B | 1B | 1B |
| 2a | $\dot{V}_A/\dot{Q}$ | 0.58 | 0.40 | 0.27 | 0.29 | 0.31 | 0.80† | 0.90 | 0.58 | 0.48 | 0.40 |
| | $\dot{V}/V$ | 3.14 | 2.48 | 0.53 | 0.39 | 0.46 | 4.58 | 4.76 | 3.11 | 1.56 | 1.62 |
| | $\dot{Q}/V$ | 132 | 106 | 61 | 53 | 41 | 120 | 150 | 92 | 83 | 59 |
| | BrS | 1 | 1 | 2 | 3 | 4 | 1 | 1 | 1‡ | 1‡ | 1‡ |
| 2b | $\dot{V}_A/\dot{Q}$ | 0.95 | 0.99 | 0.90 | 0.87 | 0.77 | 0.97 | 0.90 | 0.89 | 0.94 | 0.92 |
| | $\dot{V}/V$ | 4.50 | 5.00 | 3.42 | 2.08 | 1.01 | 4.72 | 4.26 | 4.23 | 3.17 | 3.33 |
| | $\dot{Q}/V$ | 88 | 103 | 92 | 61 | 55 | 107 | 96 | 95 | 84 | 87 |
| | BrS | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 |
| 3 | $\dot{V}_A/\dot{Q}$ | 0.99 | 1.04 | 0.99 | 0.96 | 0.95 | 1.00 | 1.03 | 0.98 | 0.69 | 0.59 |
| | $\dot{V}/V$ | 2.40 | 2.86 | 2.22 | 1.87 | 2.14 | 2.22 | 2.22 | 1.43 | 0.65 | 0.38 |
| | $\dot{Q}/V$ | 117 | 118 | 110 | 91 | 87 | 103 | 95 | 97 | 74 | 40 |
| | BrS | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 1 |
| 4 | $\dot{V}_A/\dot{Q}$ | 0.58 | 0.60 | 0.54 | 0.53 | 0.64 | 0.60 | 0.55 | 0.44 | 0.25 | 0.29 |
| | $\dot{V}/V$ | 1.84 | 1.97 | 1.69 | 1.86 | 1.91 | 1.75 | 2.14 | 0.66 | 0.13 | 0.11 |
| | $\dot{Q}/V$ | 119 | 139 | 101 | 105 | 109 | 99 | 119 | 67 | 37 | 30 |
| | BrS | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1B | 2‡ | 2 |
| 5 | $\dot{V}_A/\dot{Q}$ | 0.55 | 0.57 | 0.55 | 0.51 | 0.50 | 0.57 | 0.39 | 0.26 | 0.34 | 0.37 |
| | $\dot{V}/V$ | 1.88 | 2.38 | 2.71 | 2.81 | 2.19 | 2.22 | 1.54 | 0.50 | 0.24 | 0.33 |
| | $\dot{Q}/V$ | 85 | 96 | 118 | 112 | 121 | 101 | 117 | 90 | 41 | 63 |
| | BrS | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 4 |
| 6 | $\dot{V}_A/\dot{Q}$ | 0.55 | 0.61 | 0.62 | 0.54 | 0.51 | 0.57 | 0.61 | 0.61 | 0.45 | 0.28 |
| | $\dot{V}/V$ | 2.07 | 2.17 | 1.60 | 1.02 | 0.22 | 1.79 | 2.53 | 1.86 | 0.21 | 0.11 |
| | $\dot{Q}/V$ | 74 | 94 | 95 | 97 | 52 | 85 | 110 | 115 | 64 | 44 |
| | BrS | 1 | 1 | 1 | 4 | 2 | 1 | 1 | 1 | 3 | 4 |
| 7 | $\dot{V}_A/\dot{Q}$ | 0.73 | 0.56 | 0.40 | 0.44 | 0.49 | 0.32 | 0.40 | 0.66 | 0.54 | 0.53 |
| | $\dot{V}/V$ | 2.61 | 0.97 | 0.86 | 0.38 | 0.42 | 0.16 | 0.28 | 0.82 | 0.75 | 1.14 |
| | $\dot{Q}/V$ | 117 | 99 | 90 | 67 | 68 | 33 | 41 | 48 | 77 | 131 |
| | BrS | 2 | 2 | 3 | 4 | 5 | n.s.§ | n.s. | n.s. | n.s. | n.s. |
| 8 | $\dot{V}_A/\dot{Q}$ | 0.61 | 0.63 | 0.53 | 0.50 | — | 0.77 | 0.65 | 0.54 | 0.40 | — |
| | $\dot{V}/V$ | 0.56 | 0.67 | 0.33 | 0.39 | — | 1.67 | 1.14 | 0.36 | 0.32 | — |
| | $\dot{Q}/V$ | 69 | 88 | 47 | 47 | — | 147 | 156 | 63 | 59 | — |
| | BrS | 5 | 5 | 4 | 4 | — | 1 | 1 | 5 | 5 | — |

* Bronchographic score.
† Bold figures represent regions considered normal (*see* text).
‡ These regions contained bronchographic medium at the time of study with $^{133}$Xe.
§ Not studied.

$^{133}$Xe study. However, at the time of the $^{133}$Xe study retained bronchographic medium was scattered through the lower left lung field and may have caused the abnormal regional function. On repeat study (2b) six months later, these regions were normal (figure 2). Patient 4 also had retained bronchographic medium at the left base at the time of the $^{133}$Xe study, and it is likely

| $\dot{V}/V$ | $\dot{Q}/V$ | $\dot{V}_A/\dot{Q}$ |
|---|---|---|
| 3·14 | 132 | ·58 |
| 2·48 | 106 | ·40 |
| ·53 | 61 | ·27 |
| ·39 | 53 | ·29 |
| ·56 | 41 | ·31 |

| $\dot{V}_A/\dot{Q}$ | $\dot{Q}/V$ | $\dot{V}/V$ |
|---|---|---|
| ·80 | 120 | 4·58 |
| ·90 | 150 | 4·76 |
| ·58 | 92 | 3·11 |
| ·48 | 83 | 1·56 |
| ·40 | 59 | 1·62 |

| $\dot{V}/V$ | $\dot{Q}/V$ | $\dot{V}_A/\dot{Q}$ |
|---|---|---|
| 4·50 | 88 | ·95 |
| 5·00 | 103 | ·99 |
| 3·42 | 92 | ·90 |
| 2·08 | 61 | ·87 |
| 1·01 | 55 | ·77 |

| $\dot{V}_A/\dot{Q}$ | $\dot{Q}/V$ | $\dot{V}/V$ |
|---|---|---|
| ·97 | 107 | 4·75 |
| ·90 | 96 | 4·26 |
| ·89 | 95 | 4·23 |
| ·94 | 84 | 3·17 |
| ·92 | 87 | 3·33 |





Fig. 2. Sequential studies in Patient 2. At the top are the initial right bronchogram (*left*) and $^{133}Xe$ study (*right*). In the latter, figures representing regional $\dot{V}_A/\dot{Q}$, $\dot{Q}/V$, and $\dot{V}/V$ are placed opposite schematic counter fields shown by circles. On the bottom are the right bronchogram and $^{133}Xe$ study performed 6 months later.

| | Base $L_1$ |
|---|---|
| ) | 0.59 |
| ) | 0.98 |
| | 97 |
| | 1B |
| | 0.40 |
| | 1.62 |
| | 59 |
| | 1‡ |
| | 0.92 |
| | 3.33 |
| | 87 |
| | 1 |
| | 0.59 |
| | 0.38 |
| | 40 |
| | 1 |
| | 0.29 |
| | 0.11 |
| | 30 |
| | 2 |
| | 0.37 |
| | 0.33 |
| | 63 |
| | 4 |
| | 0.28 |
| | 0.11 |
| | 44 |
| | 4 |
| | 0.53 |
| | 1.14 |
| | 131 |
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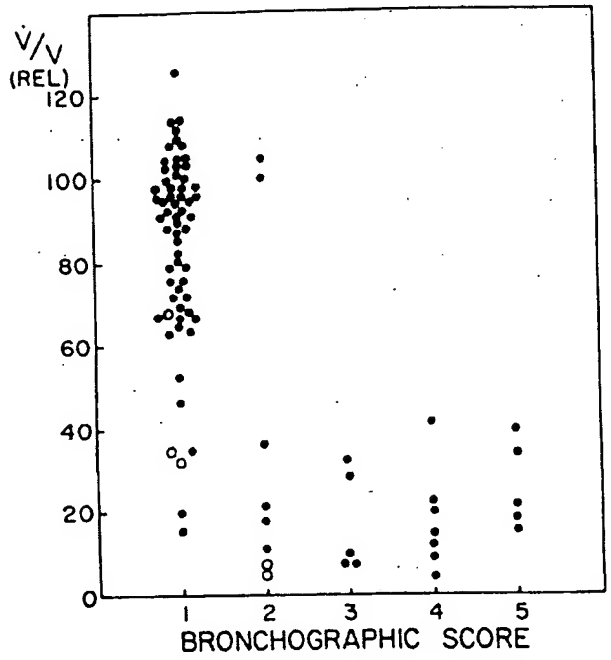


FIG. 3. Correlation of $^{133}Xe$ findings and bronchographic assessment. Ordinate: Relative regional ventilation. Abscissa: Bronchographic score. Each point represents a lung region. Open circles (○) represent regions which contained bronchographic medium at the time of the $^{133}Xe$ study; closed circles (●) represent regions which did not.

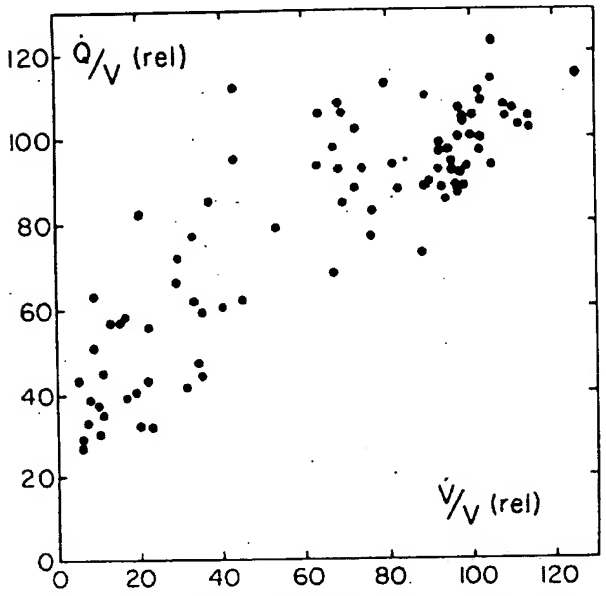


FIG. 4. Regional distribution of perfusion in bronchiectasis. Ordinate: Relative regional perfusion. Abscissa: Relative regional ventilation. Each point represents a lung region.

that its presence contributed to the extremely low V̇/V observed in these areas.

Considering the series as a whole, regional function was not closely related to the type of bronchiectasis demonstrated. In figure 3 relative regional ventilation is plotted against bronchographic score (table 2); regions with retained bronchographic medium are indicated. In general, bronchiectatic regions were less well ventilated than others. It is clear that when cylindrical bronchiectasis (grade 2) was present, regional function was quite variable, with instances of both normal and severely compromised ventilation. More severe lesions were always associated with depressed V̇/V, but the degree of hypoventilation appeared to be independent of the anatomic findings when varicose (grade 3) bronchiectasis was present.

Irrespective of bronchographic score, regions that displayed prolonged washout (low V̇/V) also demonstrated low $\dot{V}_A/\dot{Q}$. Interregional variations of $\dot{V}_A/\dot{Q}$ were considerable but were never as large as interregional variations in ventilation. This was in part explained by the fact that regional perfusion also varied with regional ventilation. In figure 4 relative regional perfusion is compared with relative regional ventilation for all patients. When relative regional ventilation was less than 60 per cent, relative regional perfusion was almost uniformly decreased.

The dependence of regional perfusion on regional ventilation is strikingly illustrated by comparing the two studies of Patient 2 (figure 2). On the first occasion, ventilation in regions $L_{1-2}$ was higher than in any other region, and only $R_1$ was as well perfused as these regions. Six months later, after the patient had stopped smoking and followed a program of antimicrobial drugs and postural drainage, ventilatory function had improved so that only $R_{4-6}$ appeared to exhibit significantly decreased ventilation and, with the exception of these regions, perfusion distribution also appeared normal. In other words, successful therapy aimed at improving ventilatory function also appeared to improve perfusion distribution.

The values of V̇/V noted in table 4 are the mean of measurements made during washout after rebreathing and after infusion. Comparison of these two washouts for each region was not meaningful in Patients 3, 4, and 6, since in these subjects, over-all ventilation was not the same during the two procedures. In the bronchiectatic regions of other patients there was no major consistent difference between V̇/V calculated from the washout of inspired $^{133}Xe$ and that

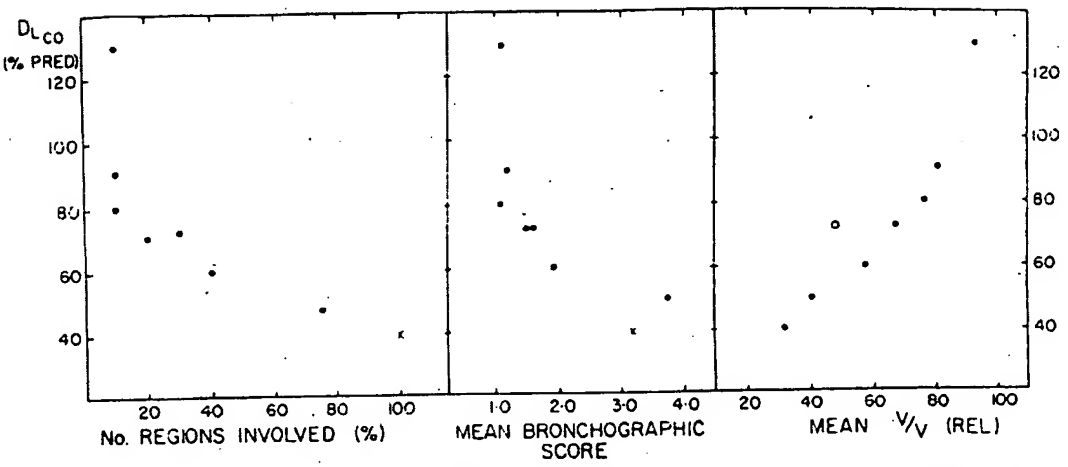


FIG. 5. Correlation of $D_{LCO}$ with $^{133}Xe$ and bronchographic results. Ordinate: steady state diffusing capacity for CO, expressed as per cent of predicted normal value. Abscissae: A. Number of lung regions which demonstrated bronchiectasis, expressed as a per cent of the total regions examined in each patient. B. Mean bronchographic score for each patient. C. Mean relative regional ventilation for each patient. Open circle (O) in panel C indicates study 2a; bronchographic medium was present in the lung of this patient during the $^{133}Xe$ study but not when $D_{LCO}$ was measured. Crosses in panels A and B represent Patient 7; bronchographic evaluation was carried out for the right lung only, while the $D_{LCO}$ presumably represented the function of both lungs.

calculated from the washout of infused $^{133}Xe$. However, in two studies, Patients 1 and 2a, discrepancies in regional washouts were seen in regions that were not bronchiectatic. The possible significance of these findings will be discussed.

In order to compare regional results with tests of over-all function, mean values of both relative regional $\dot{V}/V$ and regional bronchographic score were calculated for each patient. The first of these was thought to represent over-all ventilatory impairment; the second, the extent of bronchiectasis. These indices did not correlate well with either VC or $FEV_1$, but did with each other and with $D_{LCO}$ (figure 5). However, in each patient both $D_{LCO}$ and mean relative regional $\dot{V}/V$ correlated as well with the number of regions involved by bronchiectasis (figure 5) as with mean bronchographic score. This was of course to be expected as seen in figure 3, which indicated that the degree of regional ventilatory impairment was more dependent on the presence of bronchiectasis than on its extent.

## DISCUSSION

The results of the routine lung function tests shown in table 3 are not very different from those reported in a larger series (2). Figures for $D_{LCO}$ are somewhat lower than those of Cherniack and Carton (2), but these investigators used a single-breath test which in the presence of obstructive lung disease is known to produce values that are more nearly normal than those measured by steady-state methods (3). Our failure to find a correlation between bronchographic findings and VC and $FEV_1$ is probably due to the smallness of the series; such correlations have been found (2). The striking correlation between $D_{LCO}$ and results of both $^{133}Xe$ studies and bronchography may indicate that the steady-state $D_{LCO}$ is a particularly valuable test for patients with relatively uncomplicated bronchiectasis. We found that it correlated as well with the number of bronchiectatic regions (irrespective of the type of bronchiectasis) as it did with the mean bronchographic score, which took account of type or severity of bronchiectasis. This is precisely what has been found by Cherniack and Carton (2), who also related over-all function to bronchographic findings. These data agree with the $^{133}Xe$ findings that relative regional ventilation is independent of the anatomic type of bronchiectasis (figure 3).

As expected, bronchiectatic regions generally showed functional abnormality when studied with $^{133}Xe$. The pattern of function abnormality, i.e., low $\dot{V}/V$, $\dot{V}_A/\dot{Q}$, and $\dot{Q}/V$, was also expected. There were, however, areas of poor agreement between the $^{133}Xe$ and bronchographic studies, which fall into three groups.

First, bronchographically normal regions adjacent to bronchiectatic regions frequently

demonstrated abnormal function, e.g., Patient 3. The most obvious explanation for this phenomenon is that the spatial resolution of the $^{133}Xe$ technique was less good than that afforded by bronchography. This was very likely the case, because lung regions as studied by $^{133}Xe$ were conical, not cylindrical, and contamination of regional count rates by radiation scattered from other regions could not be prevented. Differences in spatial resolution, however, were not the only reason that the area of functional abnormality exceeded the area of anatomic bronchiectasis. Some regions bordering a lung region containing ectatic bronchi undoubtedly were supplied in part by these bronchi and therefore would be expected to function badly. It is also possible that bronchial filling was incomplete and abnormal bronchi therefore were not seen. Finally, parenchymal or pleural abnormalities might have affected regions adjacent to frank bronchiectasis. For example, Patient 3 had bronchiectasis only in $L_4$ but also showed ventilatory abnormality in both $L_3$ and $L_5$. At surgery, this patient was found to have pleural adhesions involving the entire left lower lobe; this might have limited ventilation through much of the lower left lung field.

Second, although most bronchiectatic regions were hypoventilated, some that exhibited cylindrical bronchiectasis were not. Further, the type of bronchiectatic lesion did not seem to influence the degree of hypoventilation. Over-all function was more sensitive to the amount of lung involved by bronchiectasis than to the type or intensity of bronchiectasis in any region. Again, it is possible that these results were influenced by technical problems. Thus, Patient 1 who had cylindrical bronchiectasis involving the right middle lobe ($R_4$) seemed to have normal function in this area. The anatomic lesion was situated anteriorly, and as posteriorly placed counters are relatively insensitive to such lesions, it is possible that a minor degree of right middle lobe malfunction was simply not recorded. It should be emphasized, however, that only a minor degree of malfunction could be so overlooked.

Patient 6 demonstrated much better ventilation in $R_4$, which contained varicose bronchiectasis, than she did in $R_5$, which had cylindrical disease. The explanation for this may be that the lesion in $R_4$ was well circumscribed and surrounded by presumably normal lung tissue, i.e., the bronchiectasis was subregional in $R_4$ whereas the entire counter field of $R_5$ was involved by cylindrical bronchiectasis. Once again, however, it is not likely that all the variability of function demonstrated by bronchiectatic regions can be explained on the basis of such technical factors. $^{133}Xe$ washout is importantly influenced by the status of small airways (12), the function of which may not be reflected by bronchography. For example, mucous plugging of very small (<2 mm in diameter) airways would produce functional but not necessarily bronchographic abnormality. It is of interest that bronchiectatic lung regions near the apex (Patient 8) tended to function better than those at the base, irrespective of the type of bronchiectasis, perhaps because retention of secretions was more prominent in the dependent, basal areas. The presence or absence of peripheral obstructive lesions would appear to be of crucial importance in determining the function of regions with cylindrical bronchiectasis, as in some instances such regions (Patient 1, $R_4$; Patient 7, $R_1$) showed good preservation of function, although in other regions with similar bronchographic appearance (Patient 6, $R_5$) function was severely depressed.

Third and finally, in 2, (Patients 1 and 2a) there was evidence of hypoventilation in regions that neither contained nor were adjacent to areas of bronchiectasis. These patients will be discussed later.

As regional gas tensions are dependent on regional $\dot{V}_A/\dot{Q}$ and as all patients demonstrated regions with abnormally low $\dot{V}_A/\dot{Q}$, it must be concluded that pulmonary gas exchange was not normal in these subjects. If the $\dot{V}_A/\dot{Q}$ values in table 4 are interpreted literally, it can be seen that over-all disturbances of gas exchange were minor. Such literal interpretation of regional $\dot{V}_A/\dot{Q}$ is dangerous, however, since each value represents only the mean $\dot{V}_A/\dot{Q}$ of the region and does not necessarily indicate the actual spread of $\dot{V}_A/\dot{Q}$ present. For example, consider a region consisting of two compartments of equal volume, one ventilated but not perfused ($\dot{V}_A/\dot{Q} = \infty$) and the other perfused but not ventilated ($\dot{V}_A/\dot{Q} = 0$), the mean $\dot{V}_A/\dot{Q}$ of such a region as measured with $^{133}Xe$ would be 1.0. This value, of course, is compatible with normal gas exchange, but, in fact, regional gas exchange is most abnormal. Thus regional $\dot{V}_A/\dot{Q}$ values are valid indicators of regional gas exchange only if all units within the region function in nearly the same way. It
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same way. It is difficult to test for inhomogeneity of function within single regions. One way is to compare regional washouts of inspired and infused isotope. If there are major differences in both ventilation and $\dot{V}_A/\dot{Q}$ within a region, these washouts should differ. The fact that no major systematic washout discrepancies were apparent in bronchiectatic regions may mean that there were no intraregional differences in $\dot{V}/V$ and $\dot{V}_A/\dot{Q}$ that were greater than two- or threefold (12). This is supported by the fact that arterial $P_{CO_2}$ and oxygen saturation were normal in all subjects except Patient 7.

Blood flow was not evenly distributed in these patients, but was decreased in regions that were hypoventilated, i.e., in bronchiectatic regions. This of course was expected, since obliteration of the microvasculature in areas of bronchiectasis has been well documented (10). On the other hand, functional mechanisms may have played a role in determining blood flow distribution. Hypoventilated regions had low $\dot{V}_A/\dot{Q}$ and were, therefore, relatively hypoxic. Since alveolar hypoxia is a known pressor agent for the pulmonary circulation (13), regional hypoxia might shift flow away from hypoventilated regions. The striking increase in flow to bronchiectatic regions shown by sequential study of Patient 2 indicates that such functional factors may have been important in determining flow distribution, although the nature of these factors was not demonstrated. It should be noted that the technique used in these experiments examined the distribution of the pulmonary arterial blood flow, and thereby may have underestimated total regional flow, as bronchial arterial flow to bronchiectatic areas may be considerable (14).

The sequential studies of Patient 2 present several interesting aspects. Bronchograms, routine function tests, and the results of study with $^{133}Xe$ all improved during the six months between the two studies. Part of this improvement is probably due to the fact that the initial studies were completed four weeks after an episode of right lower lobe pneumonia. Some of the bronchographic findings and the attendant functional abnormalities at the right base were therefore perhaps attributable to postpneumonic bronchiectasis that was partially reversible. The functional abnormalities at the left base in study 2a were perhaps secondary to retained bronchographic medium and therefore reversible. It is known that over-all lung function is reversibly depressed by bronchography (15), so that regional retention of radiopaque material might be expected to cause regional malfunction; this may also have been the case in region $L_4$ of Patient 5, which showed striking hypoventilation. On the first study Patient 2 showed major washout discrepancies at both the left base and right apex; washout of infused isotope was slower than that of inhaled isotope. As discussed above, this indicated that these regions were not functioning in homogeneous fashion. The pattern of the discrepency indicated that units with low $\dot{V}_A/\dot{Q}$ and $\dot{V}/V$ coexisted with other units having high $\dot{V}_A/\dot{Q}$ and $\dot{V}/V$ (12). Such an effect might have been produced by an uneven distribution of contrast medium at the left base, but the explanation of the finding at the right apex is not apparent. It is possible that these regions had been irregularly involved by bronchitis or bronchopneumonia before this study and had not yet recovered fully. At the time of the second study, washout discrepancies were not apparent.

Chronic bronchitis commonly presents a clinical picture similar to that of bronchiectasis, and bronchographic distinction is also sometimes difficult. When studied with $^{133}Xe$ certain similarities also emerge. Both produce lung regions with reduced ventilation, low $\dot{V}_A/\dot{Q}$, and somewhat reduced perfusion, and in both patient groups the abnormal regions tend to be at the lung bases (12). There were, however, differences between the groups, and these differences may be illustrated by Patient 1, who had chronic bronchitis as well as mild right middle lobe bronchiectasis. This patient showed some restriction of ventilation at both bases with slight depression of $\dot{V}_A/\dot{Q}$ at the left base. Such relatively modest decreases in regional ventilation are common in bronchitis, and figures representing regional ventilation varied from very low to normal in continuous fashion (12).

In the present series of bronchiectatics, however, such a continuous variation was not seen; rather there were essentially two kinds of regions: those with virtually normal ventilation and those in which ventilation was very severely curtailed. Thus, the degree of regional abnormality varied over a fairly wide range in bronchitics, but did not vary greatly in bronchiectatic subjects. To return to Patient 1, at the left base ventilation derived from washout after $^{133}Xe$ infusion was less than that computed from washout after rebreathing. As discussed above, this implies a

specific type of regional inhomogeneity, a type very commonly found in regions affected by chronic bronchitis but not in regions with bronchiectasis. Since this kind of washout discrepancy indicates large differences in $\dot{V}_A/\dot{Q}$ and $\dot{V}/V$ within the region, gas exchange was probably more impaired than was implied by regional values. Therefore, though bronchiectasis produces dramatic abnormalities of regional function, chronic bronchitis may produce even greater abnormalities in over-all gas exchange because of intraregional inhomogeneities.

Because of their experimental nature, no therapeutic decisions were based on the results of these $^{133}Xe$ studies. However, some evaluation of $^{133}Xe$ methods as a clinical tool in the management of bronchiectasis is possible. Patients 3 and 5 had clear-cut left lower lobe bronchiectasis, treated by resection; the results of their $^{133}Xe$ studies were in large part irrelevant to their management. Patient 6, on the other hand, had bilateral basal bronchiectasis. Although it had been decided initially to treat this patient medically, should resectional surgery be advised, it was clear that the left side should be attacked first, since function on this side was considerably worse than on the right side. Patient 8 was also treated medically, but in her case as well the course of resectional therapy was indicated by the $^{133}Xe$ studies. This patient had varicose bronchiectasis of the right upper lung field, but function in this area was better preserved than in the right lower zones, though these areas demonstrated less abnormality on bronchography. Should surgery be carried out, the right lower lobe should be excised and the right upper preserved. Thus, $^{133}Xe$ studies may be helpful for patients with bilateral disease and abnormal over-all function, in whom care must be taken to preserve a maximal amount of functional tissue.


## Summary

Eight patients with bronchiectasis underwent routine tests of over-all pulmonary function, a quantitative evaluation of regional anatomy by bronchography, and a study of regional lung function with $^{133}Xe$. Regions that demonstrated anatomic bronchiectasis showed reduced ventilation, depressed ventilation-perfusion ratios, and somewhat decreased perfusion. Although lung regions with pure cylindrical bronchiectasis exhibited extremely variable function, in general the degree of curtailment of regional ventilation appeared independent of the anatomic type of regional bronchiectasis. Thus, it appeared that disturbances in over-all lung function were dependent on the number of regions involved by bronchiectasis, irrespective of type. This was supported by correlations between both $^{133}Xe$ and bronchographic results and the steady-state $D_{LCO}$, which appeared to be a particularly sensitive test in this series. Abnormal areas tended to be larger when assessed by $^{133}Xe$ than when assessed by bronchography; this may have been partly but not wholly due to technical factors. Evidence was presented which indicated that regional distributions of bronchographic medium produced regional abnormalities of lung function.

## Resumen

*Estructura y Función Regional en la Bronquiectasia. Estudio Correlativo por Medio de la Broncografía y el $^{133}Xe$*

Se estudiaron ocho pacientes de bronquiectasia por medio de pruebas de función pulmonar rutinarias, evaluación quantitativa de la anatomía regional por broncografía, y estudio de la función regional con el $^{133}Xe$. Las áreas con bronquiectasia anatómica demostraron ventilación reducida, depresión en la razón ventilación/perfusión, y perfusión un tanto disminuída. Aunque las regiones con bronquiectasia estrictamente cilíndrica presentaban una función variable, por lo general el grado de impedimento en la ventilación regional parecía no guardar relación con el tipo anatómico de la bronquiectasia regional. De suerte, que la alteración en la función total parecía depender del número de regiones afectadas por la bronquiectasia, más bien que del tipo de ésta. Esto se desprende de la correlación entre la prueba con $^{133}Xe$ y la broncografía con la difusión del monóxido de carbono, la cual pareció ser una prueba extremadamente sensitiva en esta serie. Las áreas anormales aparecían mayores al esturdiarlas con el $^{133}Xe$ que al estudiarlas por la broncografía; esto puede haber obedecido en parte, aunque no en su totalidad, a factores técnicos. Se presenta evidencia que señala que la distribucíon regional del medio de contraste de la broncografía produjo alteraciones regionales en la función pulmonar.

## Resume

*Structure régionale et fonction chez des bronchiectasiques. Etude de corrélation avec bronchographie et $^{133}Xe$*

Huit malades atteints de bronchiectasies ont été soumis à des épreuves de routine de toute la


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fonction pulmonaire. Une évaluation quantitative de l'anatomie régionale a été menée par la bronchographie, ainsi qu'une étude de la fonction pulmonaire régionale par le $^{133}Xe$. Les régions qui présentaient des bronchiectasies anatomiques témoignaient d'une ventilation réduite, d'un abaissement des quotients ventilation-perfusion, et d'une perfusion quelque peu diminuée. En général, et quoique les régions pulmonaires présentant des bronchiectasies cylindriques pures montraient une fonction extrêmement variable, le degré de restriction de la ventilation régionale s'est révélé indépendant du type anatomique des bronchiectasies régionales. Dès lors, il ressort que les troubles de la fonction pulmonaire totale dépendent du nombre de régions atteintes par les bronchiectasies, quel que soit le type de celles-ci. La validité de cette conclusion est renforcée par les corrélations qui ont été observées entre le $^{133}Xe$ et le niveau stable de la $D_{LCO}$, ainsi qu'entre celle-ci et les résultats bronchographiques. Le niveau stable de la $D_{LCO}$ s'est révélé un signe particulièrement sensible dans cette série de malades. L'étendue des zones anormales avait tendance à paraître plus large lorsqu'elle était évaluée par le $^{133}Xe$, que lorsqu'elle était évaluée par la bronchographie; ce résultat peut être du en partie, mais pas entièrement, à des facteurs techniques. On a présenté des données qui montrent que la distribution régionale du milieu bronchographique entraîne des anomalies régionales de la fonction pulmonaire.

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